SATELLITE RETRIEVAL OF AEROSOL PROPERTIES OVER BRIGHT REFLECTING DESERT REGIONS

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ABSTRACT

Since about 30 % of the land surface are covered with arid and desert conditions of soil, bright grounds and their aerosol emissions are of essential importance for the investigation of general aerosol impact in climate. Therefore retrievals of aerosol properties from space-borne platforms need to include retrieval approaches, working over this conditions. An approach to retrieve aerosol properties over brighter surfaces such as arid and semiarid areas, based on the Bremen AErosol Retrieval (BAER) has been developed and investigated within the DREAMS Project (Dust aerosol RetrievAls from space-borne instruMentS) of SAMUM (SAharan Mineral dUst experiMent) group of researchers [1]. Combined satellite and ground based closures enable the determination of required aerosol characteristics for a remote sensing of aerosol optical thickness over bright surfaces.

Key words: SAMUM; aerosol; dust; desert.

1. INTRODUCTION

In desert regions in general the surface reflectance is very bright in the red part of visible spectrum and near infrared, however decreasing to blue range of spectrum in comparison to e.g. clouds or snow (i.e. wavelength lower 500 nm). The consideration of increased surface reflectance in lookup tables and the retrieval scheme enables a modification of the BAER approach (Bremen AErosol Retrieval) [5] to extend its application to brighter regions. Examples of aerosol optical thickness derived using the BAER algorithm over the Sahara Desert reveal various dust sources, which are important contributors to airborne dust transported over long distances. The aerosol optical thickness and surface reflectance are determined simultaneously in the algorithm using lookup tables to match the satellite observed spectral top of atmosphere radiance. Reduced Resolution Level 1 data of the Medium Resolution Imaging Spectrometer (MERIS), which is an radiometer on the ENVISAT Satellite are used, giving top of atmosphere radiance at 15 channels in the wavelength range of 412 to 900 nm. The spatial resolution of the radiometer is 1 km reduced up to 300 m full resolved. First estimates of aerosol optical thickness over arid regions are obtained for the channel 1 (412 nm). The spectral behaviour of the aerosol optical thickness depends strongly on assessed spectral surface properties and is subject of investigation.

2. THE BAER METHOD

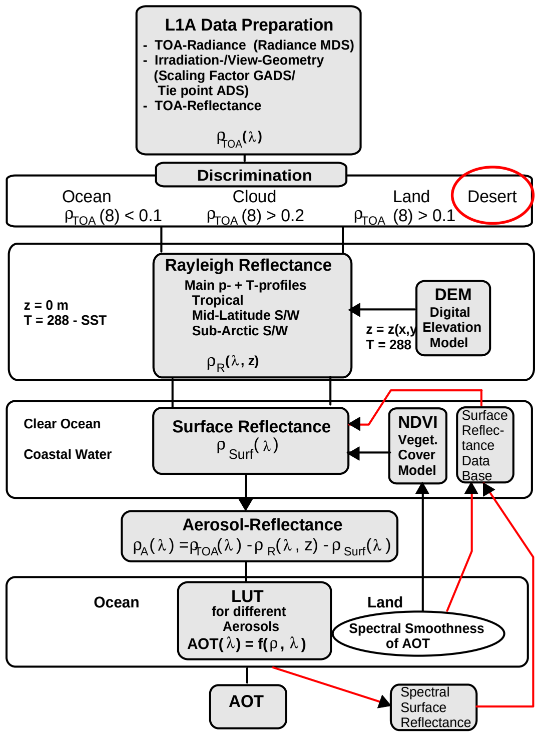

Figure 1. Overview of the steps used in the framework of the retrieval method BAER (Bremen AErosol Retrieval) for the derivation of the columnar aerosol optical thickness.

The method determines an aerosol reflectance by:

- correcting the path reflectance produced by the

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RAYLEIGH scattering, using a digital elevation model for the surface elevation,

- correcting the surface reflectance.
  Over land: using a model of a linear mixture of reflectance spectra of vegetation and bare soil, tuned by NDVI.
  Over ocean: linear mixing of coastal water and clean ocean using NDPI.
- a new land class 'Desert' has been implemented, using brighter bare soil spectra, if NDVI is near 0.
- consideration of constraints for the spectral aerosol optical thickness.

Thus, BAER retrieves spectral AOT separating aerosols from surface. Simultaneously spectral surface reflectance will be obtained.

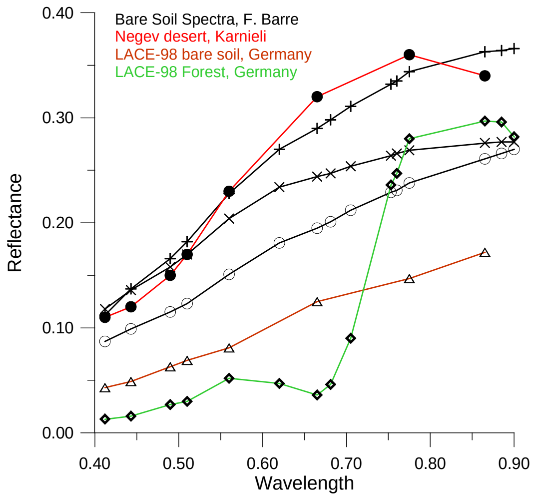

Figure 2. Surface spectra of different bare soils, showing the variability of surface properties over the desert.

The main problem is the selection and the consideration of the variability of bare soil spectra.

Radiative transfer equation:

$$\rho_{Aer}(\lambda, z_0, z_S) = \rho_{TOA}(\lambda, z_0, z_S)$$
$$- \quad \rho_{Ray}(\lambda, z_0, z_S, p_{Surf}(z))$$
$$- \quad \frac{T(\lambda, M(z_0)) \cdot T(\lambda, M(z_S)) \cdot \rho_{Surf}(\lambda, z_0, z_S)}{1 - \rho_{Surf}(\lambda, z_0, z_S) \cdot \rho_{Hem}(\lambda, z_0)}$$

where $\rho_{Aer,TOA,Surf}$ are the aerosol, top of atmosphere and surface reflectance. $\rho_{Ray}(\lambda, z_0, z_S, \rho_{Surf}(z))$ is the path reflectance of the RAYLEIGH scattering and $\rho_{Hem}(\lambda, z_0)$ is the hemispheric atmospheric reflectance. Total transmissions and hemispheric reflectance are determined by parametrisation derived from radiative transfer calculations [6]. $T(\lambda, M(z))$ is the total atmospheric transmission for the zenith distance z, containing direct and diffuse transmission for illumination z_0 and viewing geometry z_S. M is the air mass factor for sun and viewing geometry.

Surface reflectance model:

$$\rho_{Surf}(\lambda) = F_{Scale}(\rho_{TOA}(0.67\mu m))$$
$$\cdot \quad [C_{Veg} \cdot \rho_{Veg}(\lambda) + (1 - C_{Veg}) \cdot \rho_{Soil}(\lambda)]$$

$$F = \frac{\rho_{TOA}(0.665) - \rho_{Ray}(0.665) - \rho_{AER}(0.665)}{C_{Veg} \cdot \rho_{Veg}(\lambda) + (1 - C_{Veg}) \cdot \rho_{Soil}(\lambda)}$$

An overview of the main steps of the extended BAER approach is presented in Figure 1. Figure 2 gives several surface spectra, including data for bright bare soil conditions. Since the bare soil over the Sahara region is more or less the only one surface influence, the variability of the soil type directly affects the spectral AOT. Therefore a regional data set with adequate surface spectra is required. This needs to be established iteratively by the BAER approach, starting with a-priory assumptions for the region of interest.

3. RETRIEVALS OVER DESERT REGIONS

The extended BAER approach has been tested over the Sahara region during the SAMUM experiment in Ouarzazate and Zagora ("Port au Sahara") south Morocco [1]. During the SAMUM experiment (12. May - 07. June 2006), following closure measurements have been made:

- ground-based measurement for spectral AOT and sky-brightness with a CIMEL 318 sun-photometer to derive validation data and required aerosol phase functions for the desert dust,
- spectral albedo measurements from aircraft to compare the retrieved spectral surface reflectance by BAER
- top of atmosphere radiance by the MERIS instrument for the retrieval of AOT and surface reflectance by BAER and for further closure studies to derive additional aerosol parameters.

Inter-comparisons with the ground based data will be given in Section 4. First retrievals over desert region with the modified BAER are presented in this paper. Using the different starting conditions described above, first retrievals of AOT and surface reflectance over Morocco and surrounding region have been obtained. As one example, Figure 3 gives the regional pattern of AOT for MERIS channel 1 (0.412 m) over land and ocean for the MERIS scene of 31. May 2006. The corresponding RGB image is given in Figure 4. It is a case of desert dust outflow from Sahara to the Atlantic ocean, which can be observed back to the Sahara region.

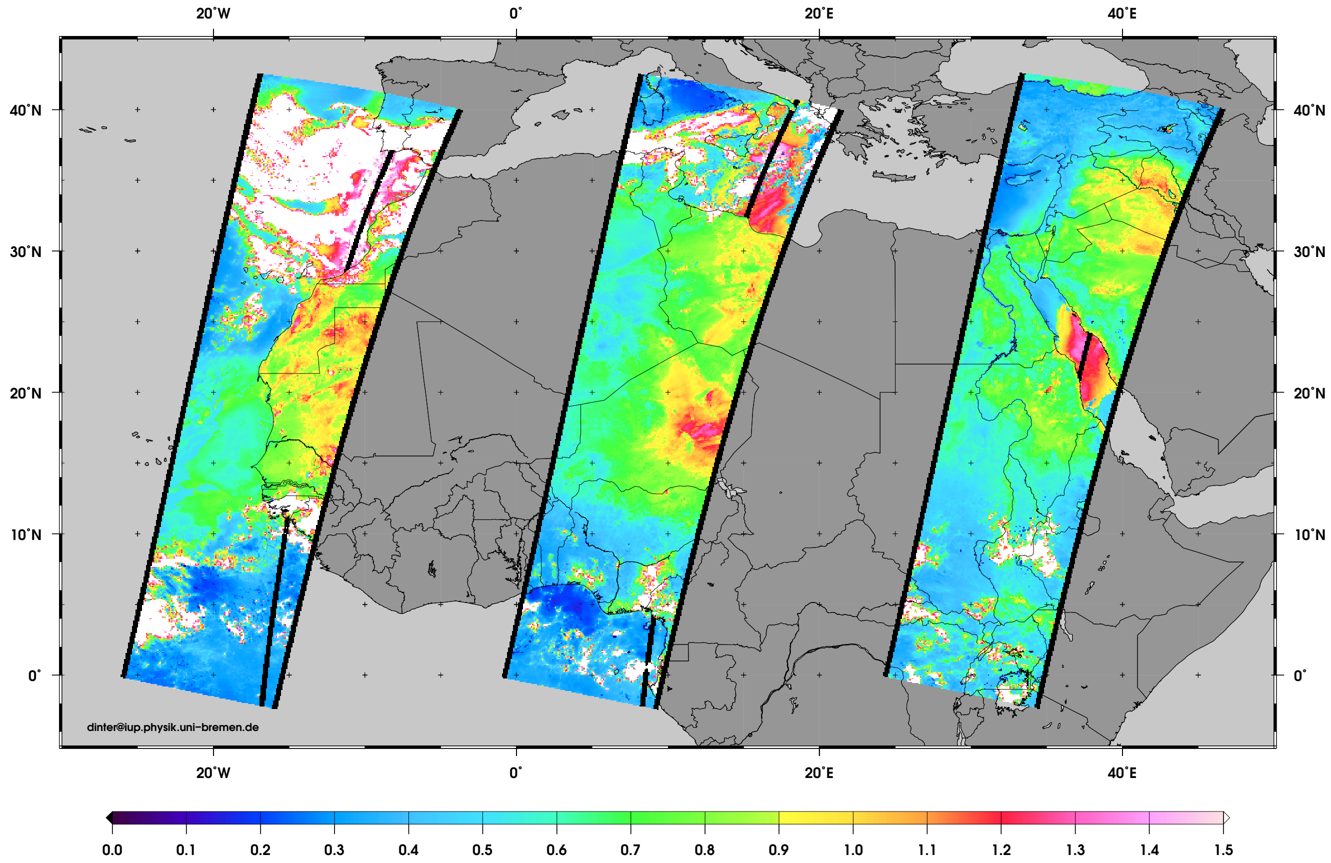

Figure 3. Aerosol optical thickness at 412 nm (channel 1) retrieved from MERIS on 31.05.2006 showing Northern Africa with aerosols source regions over the Sahara and dust outbreak over Atlantic ocean. For the land class 'Desert' one surface spectrum with the highest spectral slope is assessed. Inside the swath over ocean water the theoretical sun glint pattern is marked with a black line. The width of the real sun glint region is caused by the roughness of the oceanic surface and leads to an overestimation of AOT.

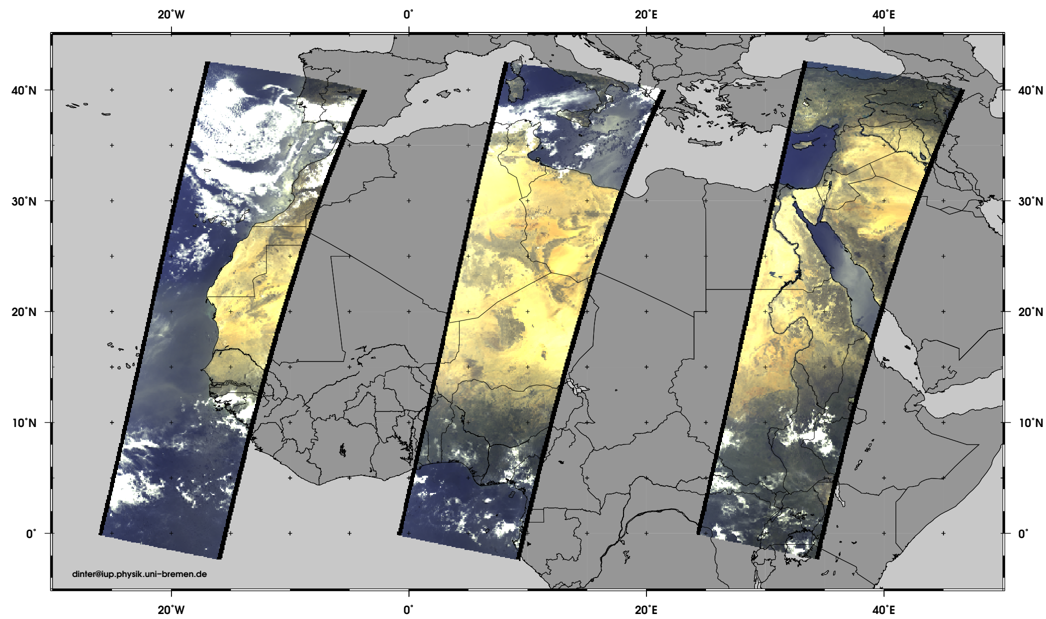

Figure 4. RGB composition of channels 1-7 for the same scene as in Figure 3.

4. COMPARISON SATELLITE AND GROUND BASED MEASUREMENTS

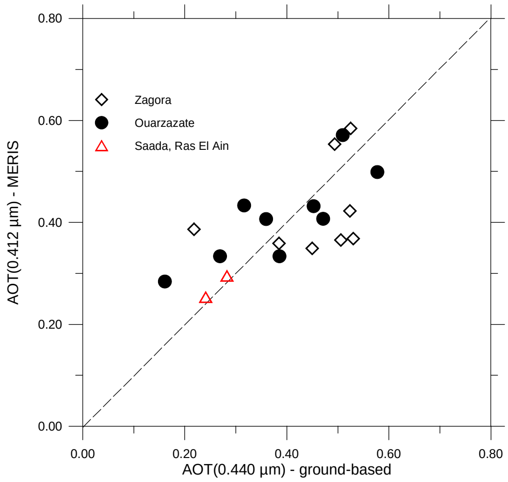

Figure 5. AOT from CIMEL ground based measurements versus MERIS AOT retrievals during SAMUM campaign.

A preliminary validation of AOT for all MERIS overflights during the SAMUM campaign (12.05.2006 – 07.06.2006) in Morocco are given in Figure 5. The two sun photometers for ground based AOT measurements were placed in Ouarzazate and Zagora. Another AERONET station (Saada) is taken into account.
In Figures 6 and 7 comparisons of spectral slopes between AOT from satellite and CIMEL and surface reflectance from satellite and aeroplane are shown.

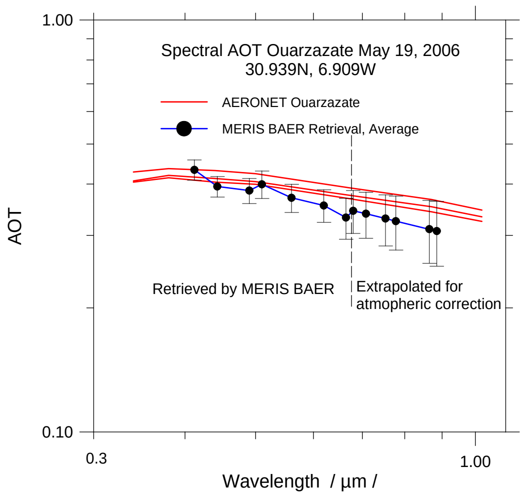

Figure 6. Comparison of spectral AOT from CIMEL ground based measurements and MERIS AOT retrievals over Ouarzazate for MERIS overflight 19.05.2006 10:51 UTC.

Examples of calculated Phasefunctions are shown in Figure 8. The Phasefunctions are calculated from ground based CIMEL sky brightness measurements by using an inversion model based on a semi empirical Pollack&Cuzzi approach [4]. The curve shape shows a very smooth behaviour in the backward scattering region and no back scattering peak.

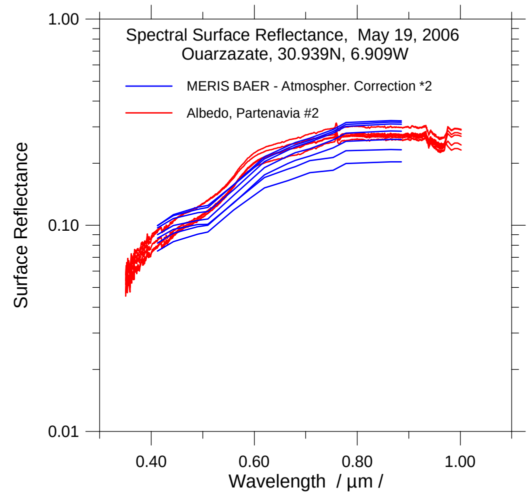

Figure 7. Comparison of retrieved (by BAER) spectral surface reflectance with albedo measurements of aeroplane flight project during SAMUM campaign, for MERIS overflight 19.05.2006 10:51 UTC.

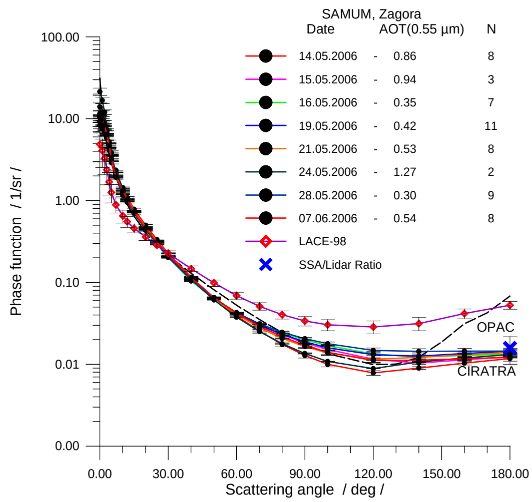

Figure 8. Phasefunctions of CIMEL sky brightness measurements calculated by inversion model using a semiempirical Pollack&Cuzzi approach [4]. Value of 180° is compared with derived value from lidar ratio.

5. SAMUM AND AERVAL

Several research institutes in Germany are participating in SAMUM project, in cooperation with the Mohammed I. University (Oujda, Morocco), funded by the

German Research Foundation (Deutsche Forschungsgemeinschaft, DFG). Thereby AERVAL (Determination of optical properties of desert dust AERosol for satellite VALidation) is a sub project and one contribution of the Institute of Environmental Physics of the University Bremen to the SAMUM main project. AERVAL focuses on long term measurements in Morocco and analyses effects of mineral dust from the Saharan desert on the atmospheric radiation budget.

6. SUMMARY

First retrievals of aerosol optical thickness over arid and semiarid Saharan desert regions are obtained for the channel 1 (412 nm) of the MERIS instrument onboard ENVISAT. These results are encouraging.
The spectral behaviour of the aerosol optical thickness depends strongly on assessed spectral surface properties and is subject of further investigation.

Questions to be answered:

- What is the remaining effect of the variability of surface reflectance ?
- What accuracy of AOT can be achieved over deserts ?
- Is the spectral slope of AOT observable ?

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